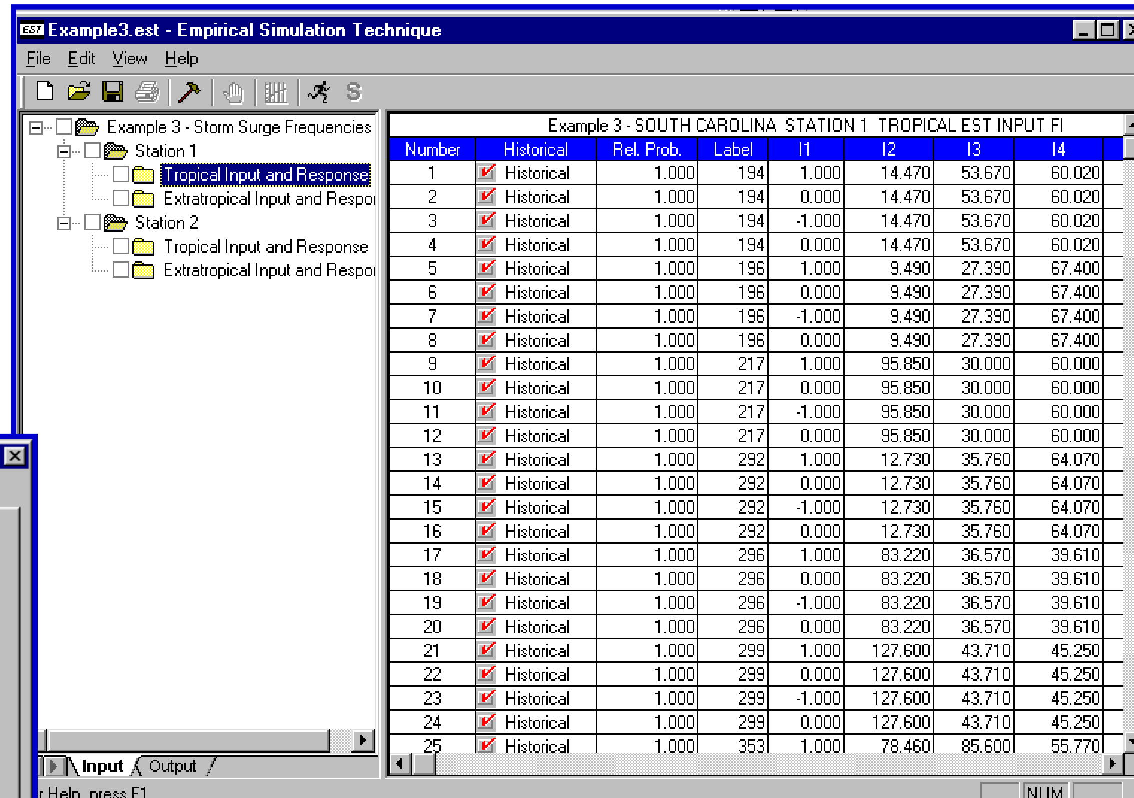
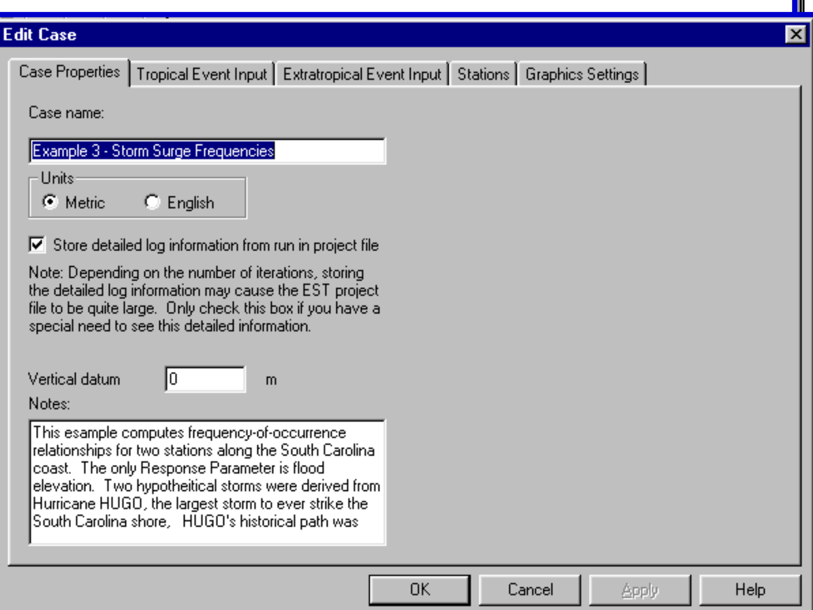
Empirical Simulation Technique

Perform life-cycle analysis of storm impacts

- flood frequency
- beach / dune recession
- disposal site analysis
- scour at bridge piles



Number	Historical	Rel. Prob.	Label	I1	I2	I3	I4
1	Historical	1.000	194	1.000	14.470	53.670	60.020
2	Historical	1.000	194	0.000	14.470	53.670	60.020
3	Historical	1.000	194	-1.000	14.470	53.670	60.020
4	Historical	1.000	194	0.000	14.470	53.670	60.020
5	Historical	1.000	196	1.000	9.490	27.390	67.400
6	Historical	1.000	196	0.000	9.490	27.390	67.400
7	Historical	1.000	196	-1.000	9.490	27.390	67.400
8	Historical	1.000	196	0.000	9.490	27.390	67.400
9	Historical	1.000	217	1.000	95.850	30.000	60.000
10	Historical	1.000	217	0.000	95.850	30.000	60.000
11	Historical	1.000	217	-1.000	95.850	30.000	60.000
12	Historical	1.000	217	0.000	95.850	30.000	60.000
13	Historical	1.000	292	1.000	12.730	35.760	64.070
14	Historical	1.000	292	0.000	12.730	35.760	64.070
15	Historical	1.000	292	-1.000	12.730	35.760	64.070
16	Historical	1.000	292	0.000	12.730	35.760	64.070
17	Historical	1.000	296	1.000	83.220	36.570	39.610
18	Historical	1.000	296	0.000	83.220	36.570	39.610
19	Historical	1.000	296	-1.000	83.220	36.570	39.610
20	Historical	1.000	296	0.000	83.220	36.570	39.610
21	Historical	1.000	299	1.000	127.600	43.710	45.250
22	Historical	1.000	299	0.000	127.600	43.710	45.250
23	Historical	1.000	299	-1.000	127.600	43.710	45.250
24	Historical	1.000	299	0.000	127.600	43.710	45.250
25	Historical	1.000	353	1.000	78.460	85.600	55.770



EST Presentation Topics

- Overview of EST
- Beginning a New Session
- Graphics Settings
- Building Input and Response Parameters
- Running EST
- Visualization

Overview of EST – What does it do?

- Procedure for simulating multiple life-cycle sequences of non-deterministic multi-parameter systems
- Based on a "Bootstrap" resampling-with-replacement, interpolation, and subsequent smoothing technique
- Employs random sampling of a finite length database to generate a larger database

Example:

Storm events and their corresponding environmental impacts

What does this mean?

- A generalized risk analysis procedure for any cyclic or frequency-related phenomena

- Applications include risk / frequency of:
  - Flood levels due to storms
  - Erosion of dredged material mounds
  - Storm-induced beach / dune erosion
  - Scour at bridge piles due to extreme currents
  - ETC! Applications are endless

- Basic assumption: future events statistically similar in magnitude & frequency to past events

Procedure

- Start with analysis of historical events that have impacted a specific locale (for simplicity, this presentation is restricted to flood frequency analysis)
- Select a database of storm events for your project site
- Parameterize events in some way to define their characteristics and impacts
    - Parameters that define the storms are referred to as Input Vectors
    - Response Vectors define storm-related impacts
- Input & response vectors are used as the basis for generating life-cycle simulations of storm-event activity with corresponding impacts

Input Vectors for Tropical Storms

Input vectors describe the physical characteristics of the storm event & the location of the event with respect to the project site.

For a tropical storm input vectors or storm parameters might include:

- **central pressure deficit**
- **radius to maximum winds**
- **maximum wind velocity**
- **minimum distance from the eye of the storm to the project site (track)**
- **forward speed of the eye**
- **tidal phase and amplitude during the event**
- **ETC!**

Input Vectors for ExtraTropical Storms

Parameters for an extratropical storm might include:

- duration of event as measured by some threshold damage criteria
- associated wind wave heights and periods
- tidal phase and amplitude
- storm surge elevation with no tidal contribution
- ETC!

Note: Input vectors are not limited to those described; they can be any physical attribute of the overall system that may affect the response of the system. For example, in some applications rainfall and river stage could be included as input vectors since their values influence the computed distribution of high water within a basin.

Response Vectors

Response vectors define storm-related impacts such as inundation and shoreline / dune erosion. Both tropical & extratropical storms might include:

- **maximum surge or flood elevation**
- **shoreline erosion**
- **dune recession**
- **ETC!**

Response vectors are related to input vectors BUT the interrelationship is

- **highly nonlinear**
- **involve correlation relationships that cannot be directly defined, i.e., nonparametric**

More on Response Vectors

For example, in addition to storm input parameters storm surge is a function of

- local bathymetry
- shoreline slope and exposure
- spatial and temporal gradients of ocean currents, temperature, etc.

It is assumed these combined effects are reflected by the response vectors even though their individual contribution to the response is unknown.

Response parameters are usually not available from post-storm records at the spatial density required for a frequency analysis.

Additional Tools Needed

Therefore, response vectors are generally computed via numerical models. For example:

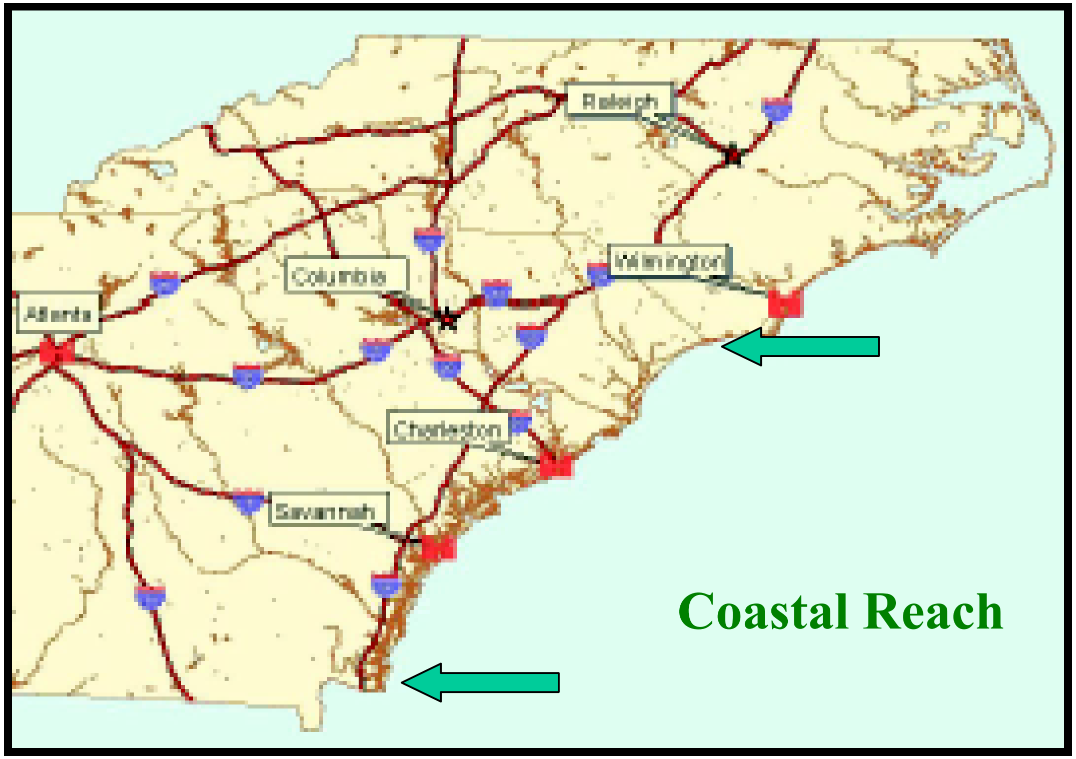
- maximum surge elevation may require a hydrodynamic model coupled to a tropical storm model or databases containing extratropical wind fields
- storm-related erosion may require additional models to compute berm / dune erosion

Typical models for simulating response phenomena might be:

ADCIRC, DYNLET, STWAVE, SBEACH, GENESIS, ETC!

Implementation of EST

Compute flood elevation frequency for the State of South Carolina



Data Search

Goal: Determine stage-frequency relationships at 38 coastal locations

Key: Develop an appropriate database of storms and their impacts

For tropical storms the NOAA "HURDAT" database covers 150 years of tropical storm information impacting the east and Gulf coast of the U.S.

EST contains the HURDAT database

HURDAT

NOAA's HURricane DATabase

- Impact areas: U.S. East / Gulf coasts & Caribbean sea
- Coverage: 1851 to present (through 2001 in CEDAS)
- Data available in 6-hr intervals:
  - latitude / longitude of tropical storm eye
  - central pressure
  - maximum wind speed

- Caution: storm data may be sparse – 19th century.
- View the data for each analyzed storm to help determine if it should be included in your database of storms.
- Export the storm analysis results in an ASCII form that complies with EST input format.

SC Input Vectors

The EST interface has a mechanism to interrogate this database and determine appropriate events. Before selecting the storms you must decide which storm parameters you will use as the "input vectors" for your simulation. In the S.C. study the following were selected:

I1 – tidal phasing

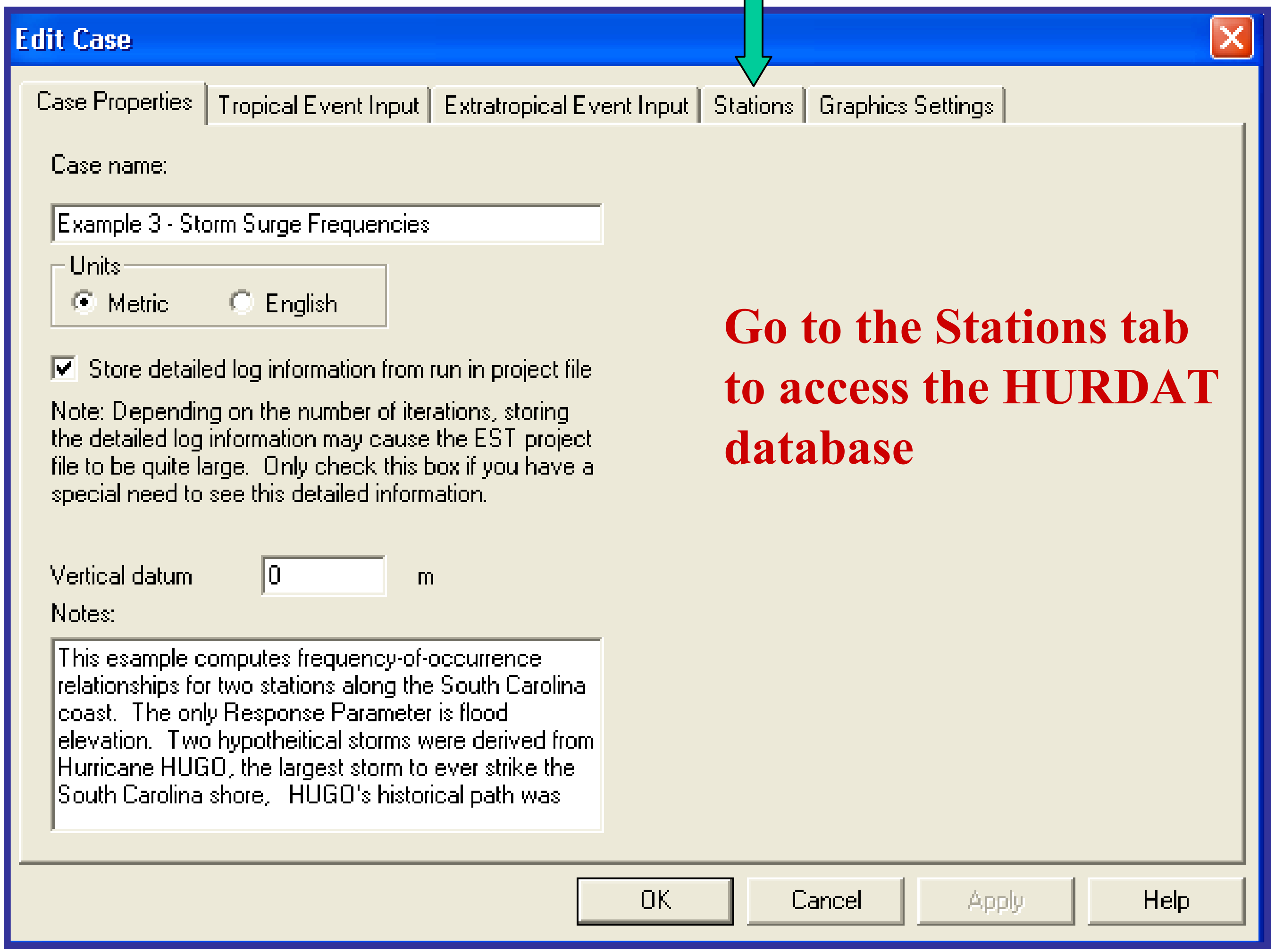
I2 – distance from eye

I3 – central pressure deficit

I4 – max wind speed

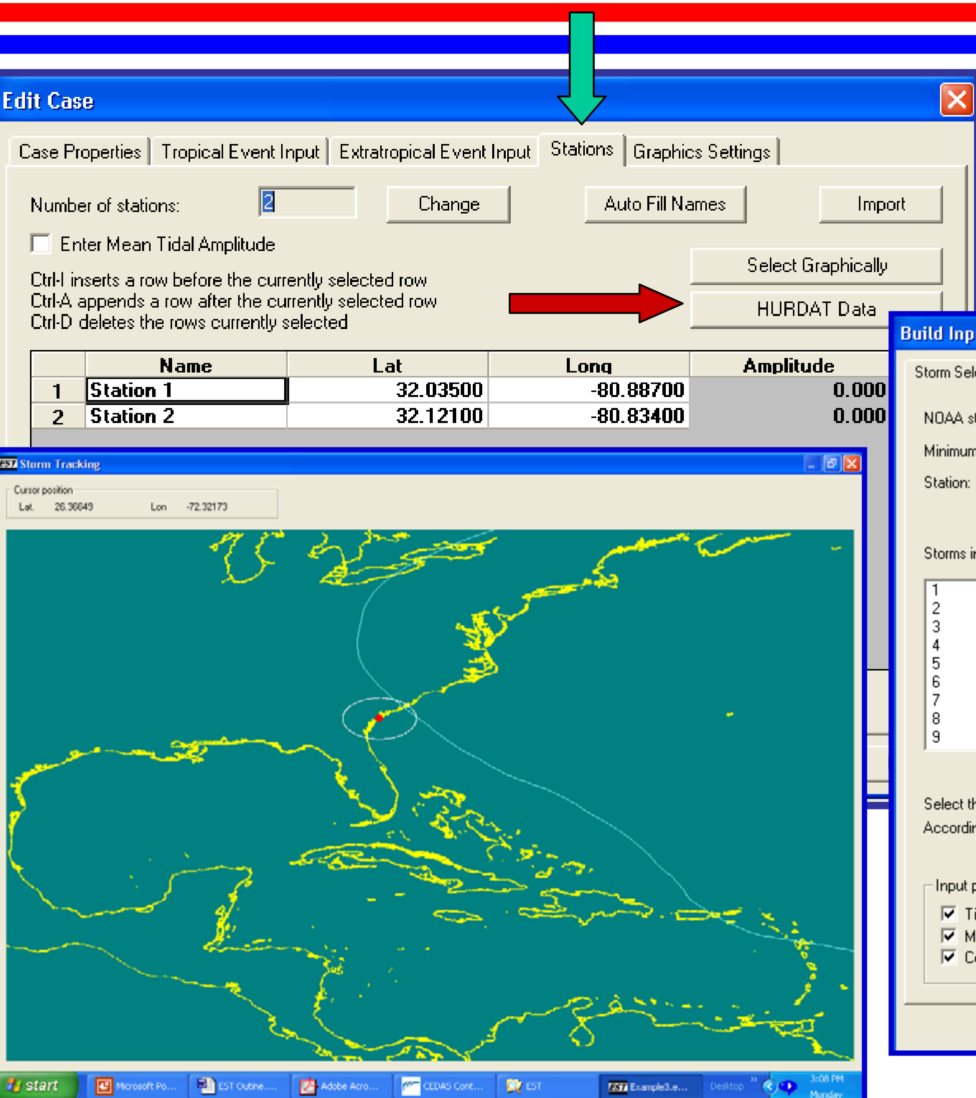
I5 – forward speed

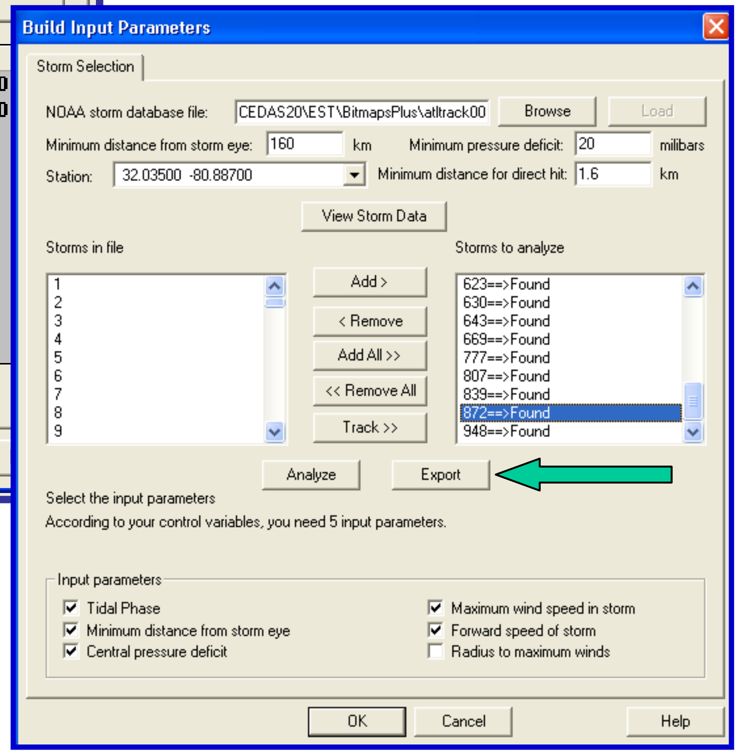
Edit Data Screen



Go to the Stations tab to access the HURDAT database

Storm Analysis





Storm Analysis

1 - specify criteria, input parameters, & station location

2 - select storms from the file to analyze / identify candidates

3 - select / export your storm set

Augmentation

<u>Ideally</u>: historical data will be adequate insofar that it includes both the number of events and the severity of events as measured by their descriptive parameters. Experience shows this is usually not the case.

Steps in selecting an appropriate storm set:

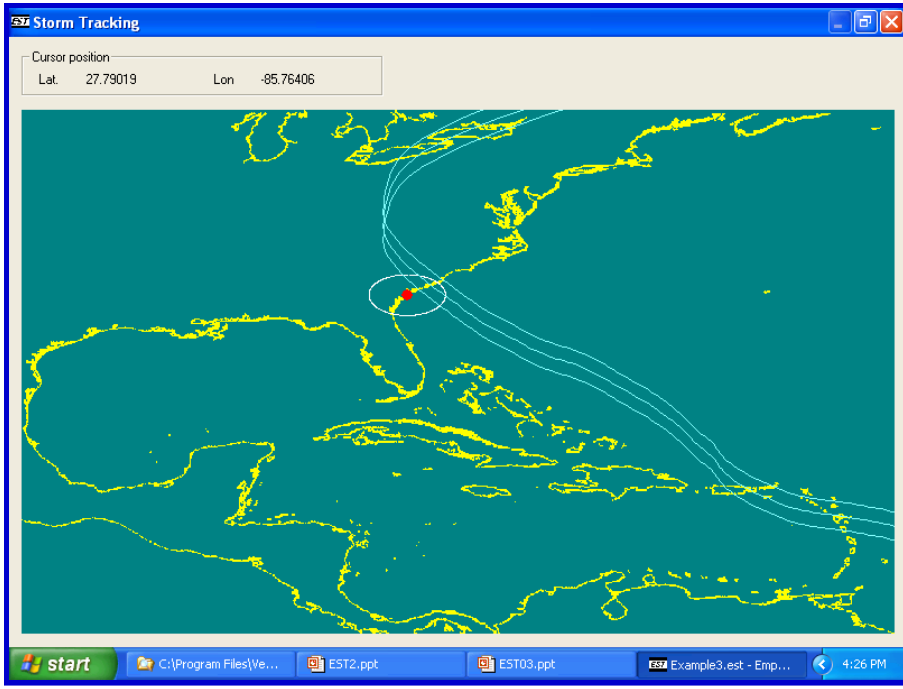
- **Remove redundant events**
- **Augment the database with historical "like" storms (necessary for very sparse databases)**

Historical "like" storms: storms that could have occurred

Training Set

Example historical "like" storms

- one with a slightly altered path
- one with increased/decreased radius to maximum wind
- ETC.

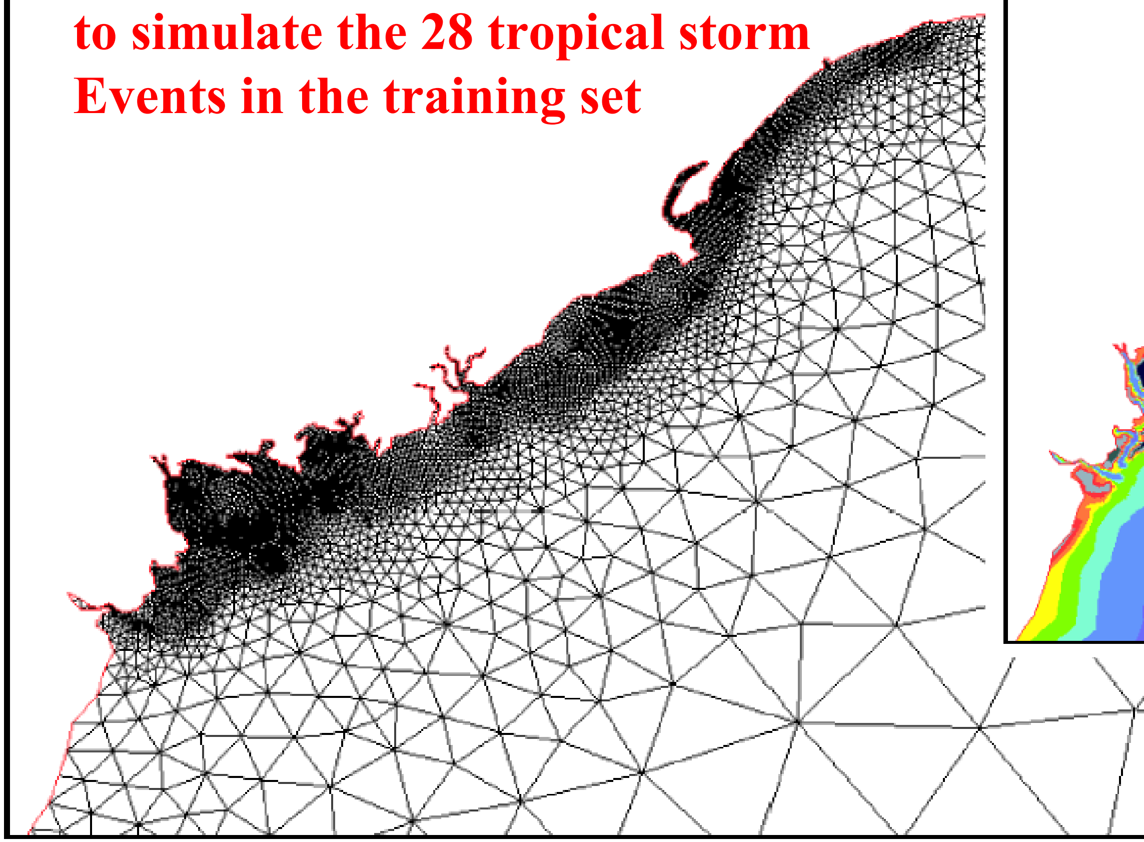


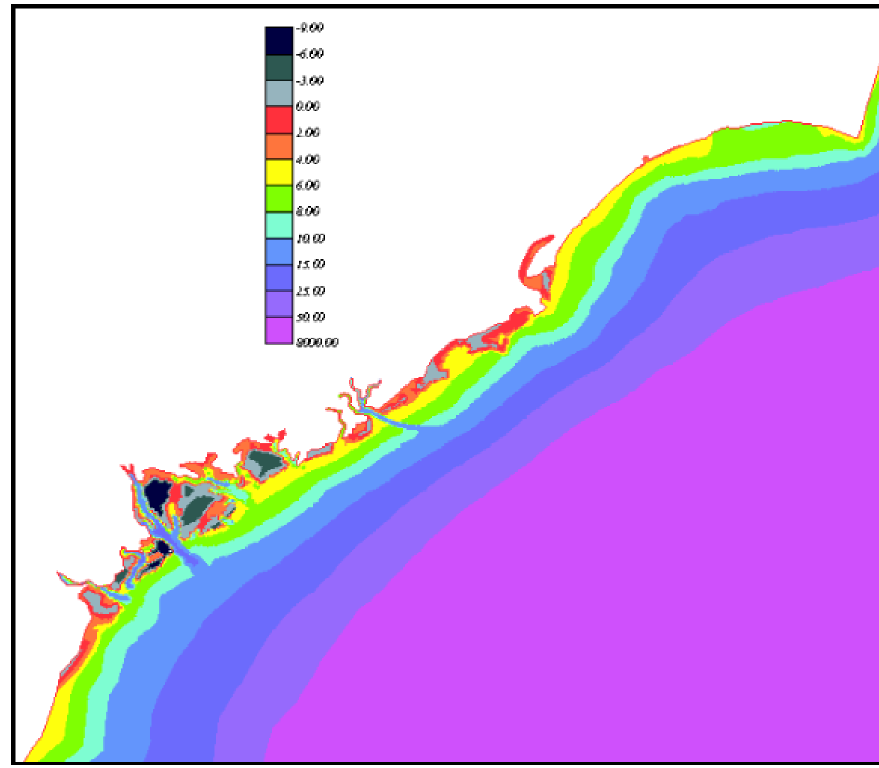
Assignment of probability to these historical "like" storms will be covered later.

The set of storms to be use for EST simulations is referred to as the **training set**.

ADCIRC Simulations

ADCIRC was used in the SC study to simulate the 28 tropical storm Events in the training set





Storm Event Consistency

AXIOM: future events similar to past events

- training set contains events the same as or similar to historical events
- EST approach selects a sample storm based on a random number selection from 0 to 1
- performs a random walk from an event X_i with x_1 and x_2 response vectors to the nearest neighbor vectors
- walk is based on independent uniform random numbers on (-1,1)

This procedure has the effect of simulating responses that are not identical to the historical events but are similar to events that have historically occurred.

Storm Event Frequency

AXIOM: storm occurrence similar to historical

Poisson distribution determines the average number of expected events in a given year.

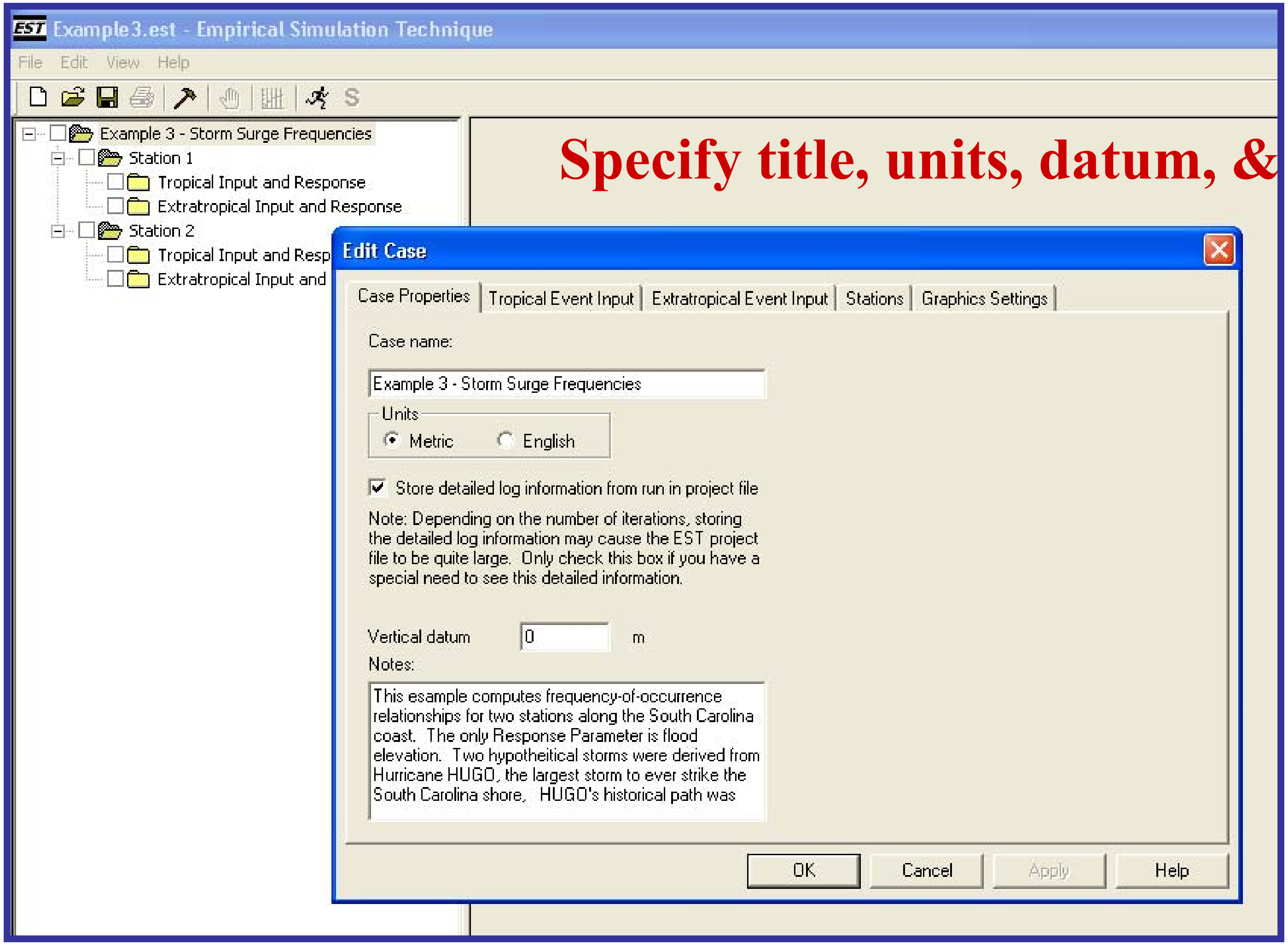
$$Pr(s;\lambda) = \frac{\lambda^s e^{-\lambda}}{s!}$$

where Pr defines the probability of having s events per year and λ is the historically based number of events per year

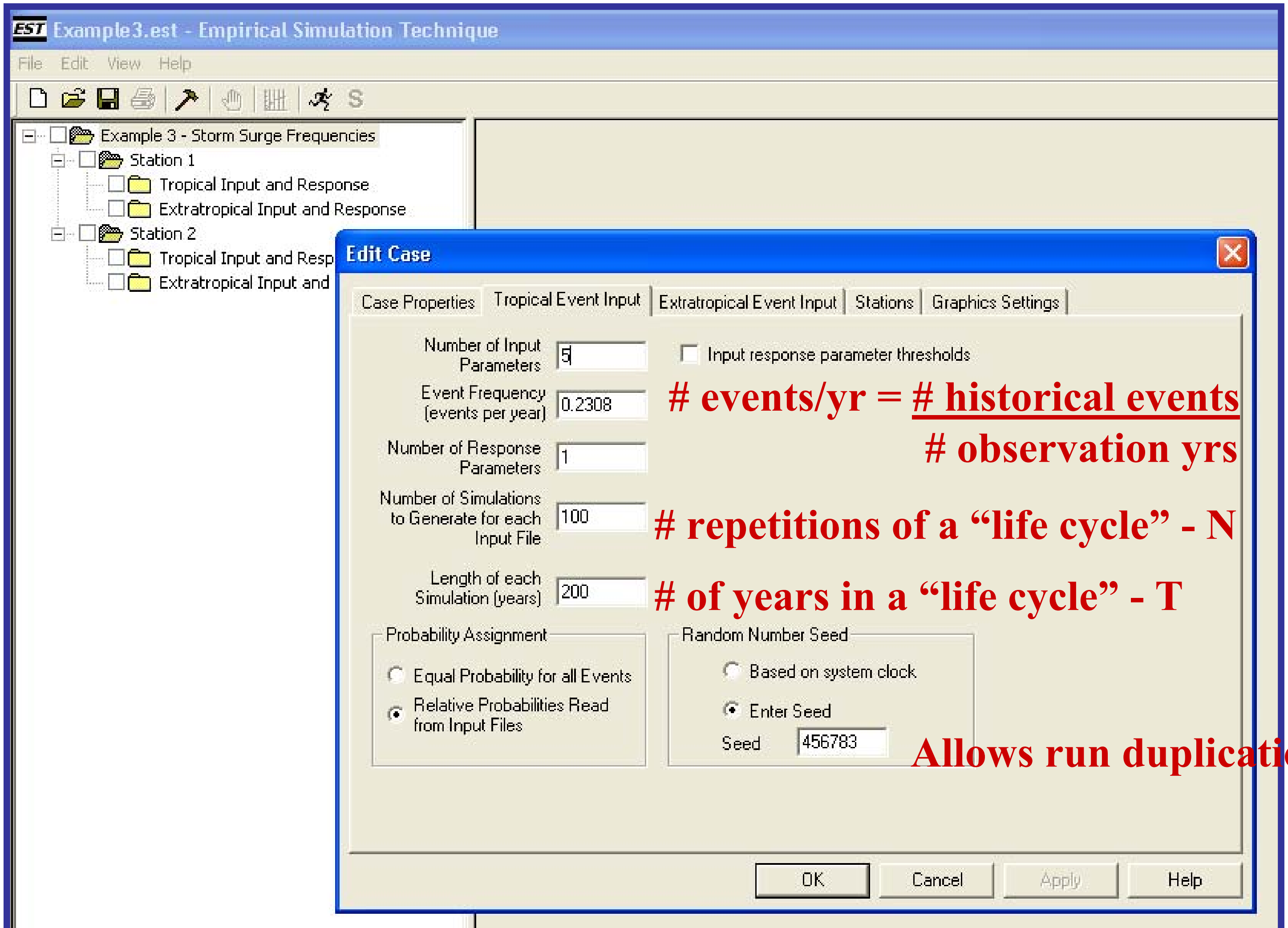
Output from the EST program is N repetitions of a life cycle of T-years of simulated storm event responses

Beginning a New Session

Specify title, units, datum, & case notes



Set Tropical Storm Parameters



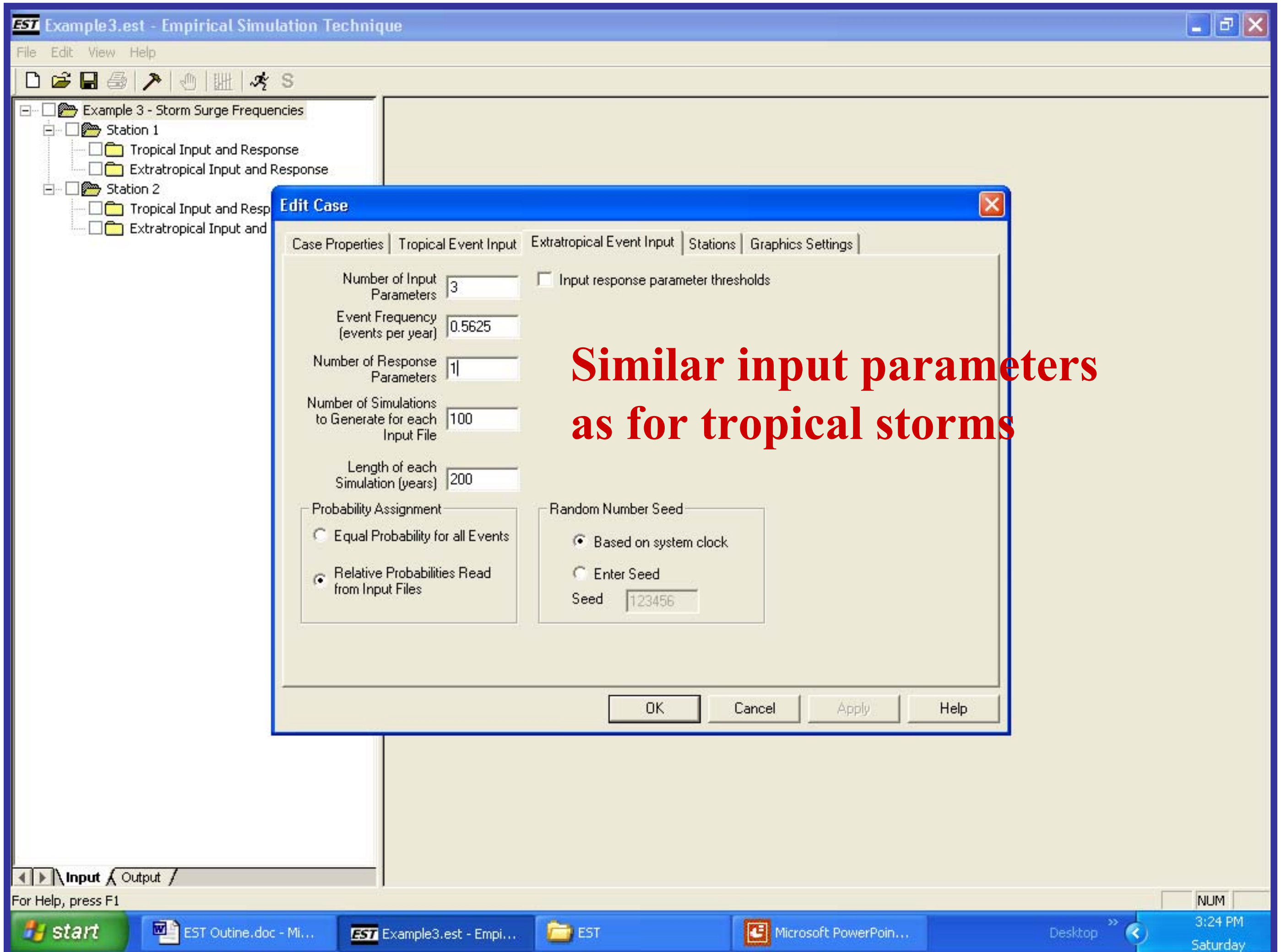
$$\text{\# events/yr} = \frac{\text{\# historical events}}{\text{\# observation yrs}}$$

repetitions of a "life cycle" - N

of years in a "life cycle" - T

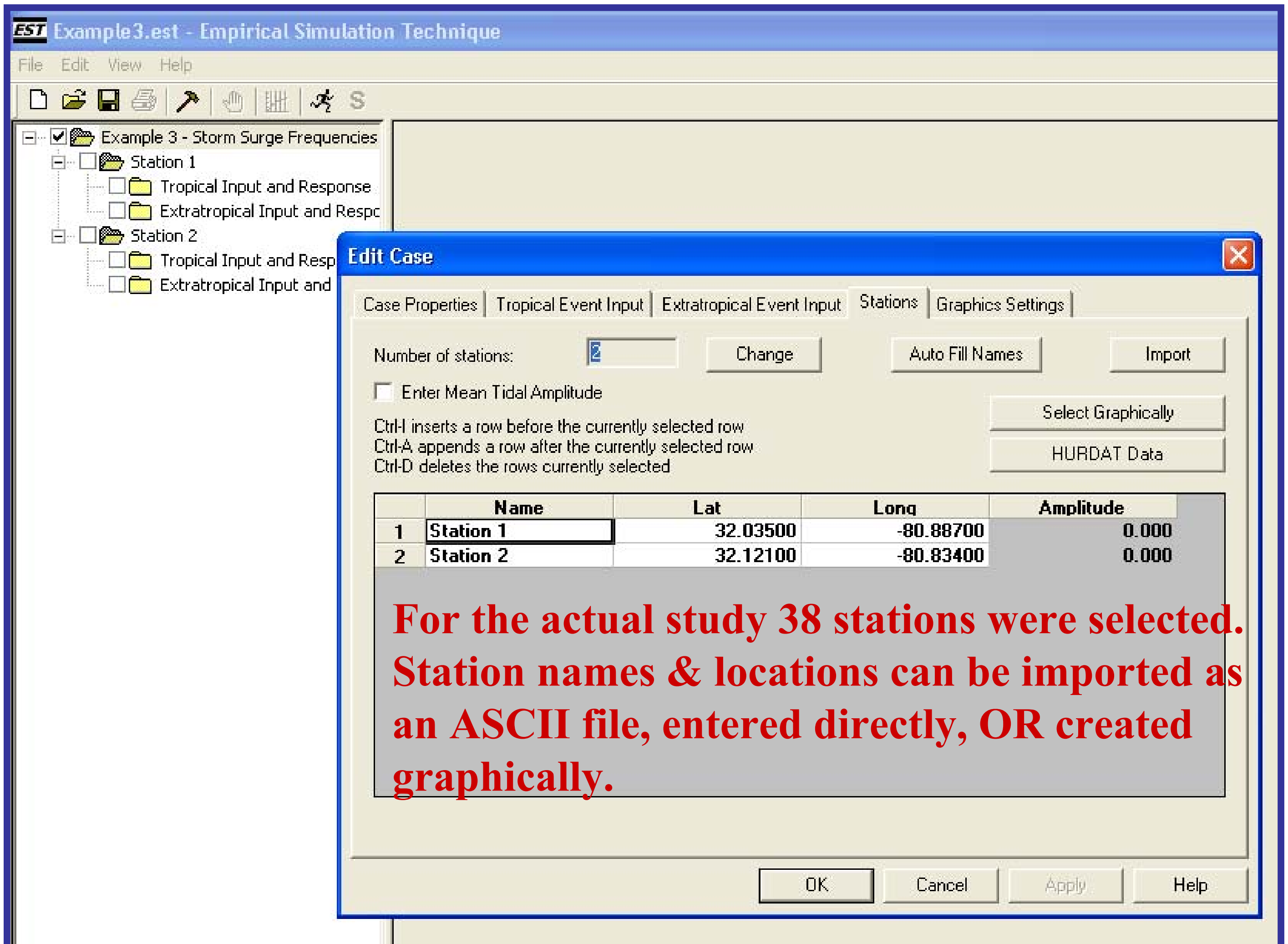
Allows run duplication

Set ExtraTropical Storm Parameters



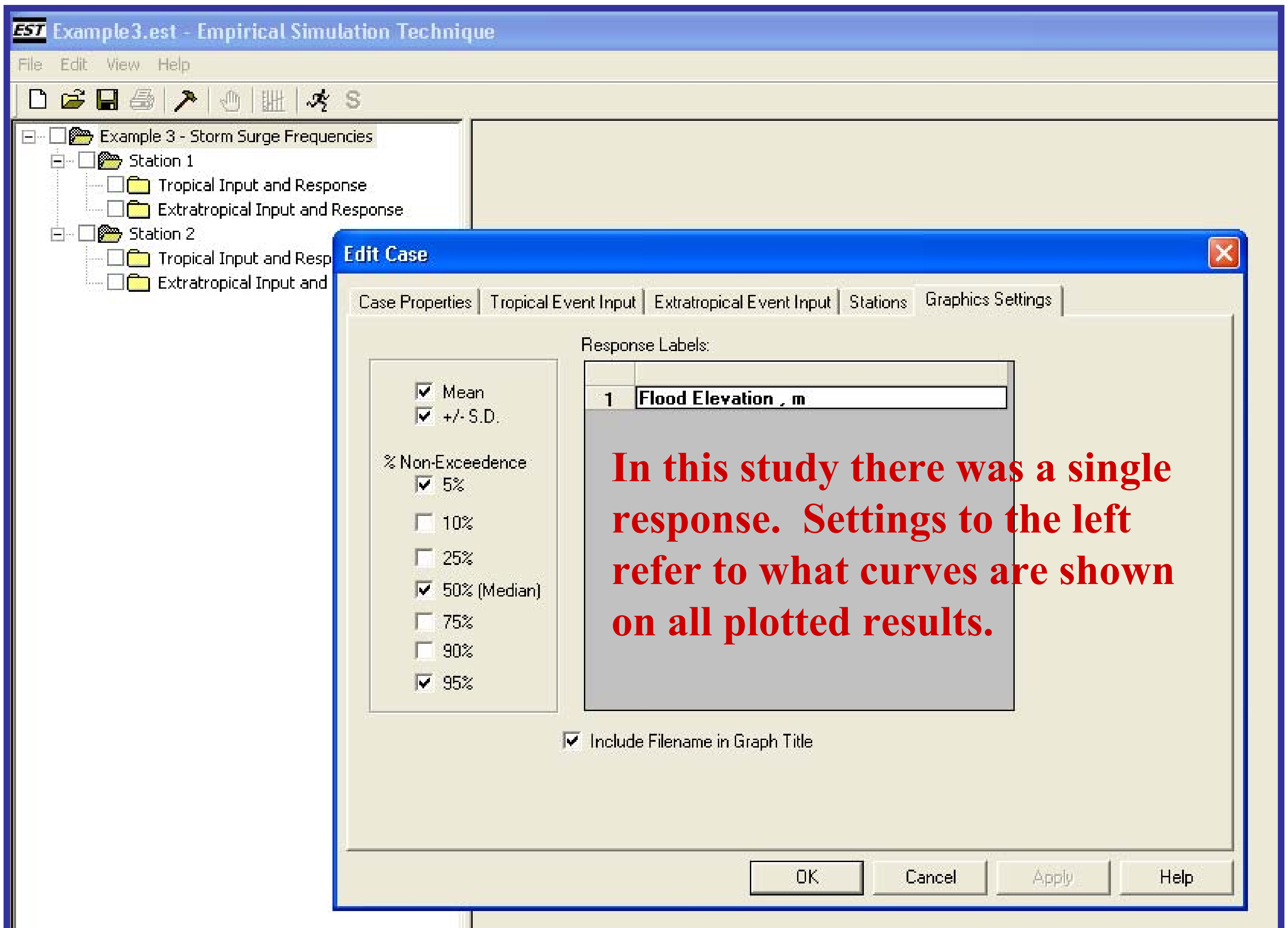
Similar input parameters as for tropical storms

Define Station Locations



For the actual study 38 stations were selected. Station names & locations can be imported as an ASCII file, entered directly, OR created graphically.

Set Graphics Controls



In this study there was a single response. Settings to the left refer to what curves are shown on all plotted results.

EST Input

Example3.est - Empirical Simulation Technique

File Edit View Help

- Example 3 - Storm Surge Frequencies
  - Station 1
    - Tropical Input and Response
    - Extratropical Input and Response
  - Station 2
    - Tropical Input and Response
    - Extratropical Input and Response

Example 3 - SOUTH CAROLINA STATION 1 TROPICAL EST INPUT FI

Number	Historical	Rel. Prob.	Label	I1	I2	I3	I4	I5	R1
76	Historical	1.000	643	0.000	5.930	21.990	40.360	10.110	0.610
77	Historical	1.000	669	1.000	86.130	47.000	75.000	19.190	1.780
78	Historical	1.000	669	0.000	86.130	47.000	75.000	19.190	0.840
79	Historical	1.000	669	-1.000	86.130	47.000	75.000	19.190	-0.100
80	Historical	1.000	669	0.000	86.130	47.000	75.000	19.190	0.840
81	Historical	1.000	777	1.000	17.950	42.320	72.770	9.630	2.460
82	Historical	1.000	777	0.000	17.950	42.320	72.770	9.630	1.520
83	Historical	1.000	777	-1.000	17.950	42.320	72.770	9.630	0.580
84	Historical	1.000	777	0.000	17.950	42.320	72.770	9.630	1.520
85	Historical	1.000	797	1.000	39.520	20.000	41.970	14.570	1.300
86	Historical	1.000	797	0.000	39.520	20.000	41.970	14.570	0.360
87	Historical	1.000	797	-1.000	39.520	20.000	41.970	14.570	-0.580
88	Historical	1.000	797	0.000	39.520	20.000	41.970	14.570	0.360
89	Historical	1.000	839	1.000	46.870	22.010	48.600	21.280	1.210
90	Historical	1.000	839	0.000	46.870	22.010	48.600	21.280	0.270
91	Historical	1.000	839	-1.000	46.870	22.010	48.600	21.280	-0.670
92	Historical	1.000	839	0.000	46.870	22.010	48.600	21.280	0.270
93	Historical	0.200	872	1.000	85.280	68.900	98.390	23.330	1.440
94	Historical	0.200	872	0.000	85.280	68.900	98.390	23.330	0.500
95	Historical	0.200	872	-1.000	85.280	68.900	98.390	23.330	-0.440
96	Historical	0.200	872	0.000	85.280	68.900	98.390	23.330	0.500
97	Historical	0.200	873	1.000	85.280	68.900	98.390	23.330	4.770
98	Historical	0.200	873	0.000	85.280	68.900	98.390	23.330	3.830
99	Historical	0.200	873	-1.000	85.280	68.900	98.390	23.330	2.890
100	Historical	0.200	873	0.000	85.280	68.900	98.390	23.330	3.830
101	Historical	0.200	874	1.000	85.280	68.900	98.390	23.330	1.430
102	Historical	0.200	874	0.000	85.280	68.900	98.390	23.330	0.490
103	Historical	0.200	874	-1.000	85.280	68.900	98.390	23.330	-0.450
104	Historical	0.200	874	0.000	85.280	68.900	98.390	23.330	0.490
105	Historical	0.200	875	1.000	85.280	68.900	98.390	23.330	1.380
106	Historical	0.200	875	0.000	85.280	68.900	98.390	23.330	0.440
107	Historical	0.200	875	-1.000	85.280	68.900	98.390	23.330	-0.500
108	Historical	0.200	875	0.000	85.280	68.900	98.390	23.330	0.440
109	Historical	0.200	876	1.000	85.280	68.900	98.390	23.330	1.210
110	Historical	0.200	876	0.000	85.280	68.900	98.390	23.330	0.270
111	Historical	0.200	876	-1.000	85.280	68.900	98.390	23.330	-0.670
112	Historical	0.200	876	0.000	85.280	68.900	98.390	23.330	0.270

HUGO

Columns of the storm database:

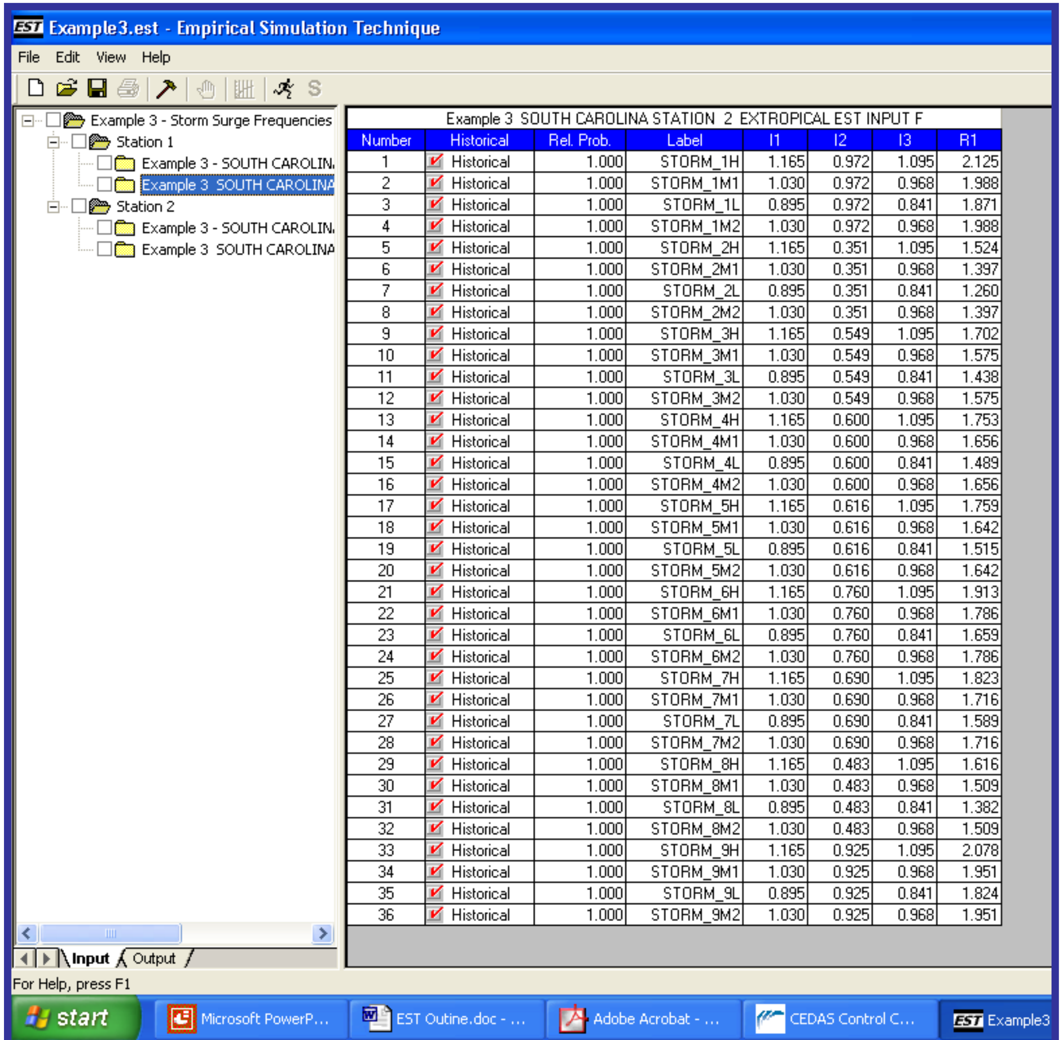
- # of event
- Historical or not
- Relative probability
- Storm name
- I1 – tidal phasing
- I2 – distance from eye
- I3 – central pressure deficit
- I4 – max wind speed
- I5 – forward speed
- R1 – max water elevation

Input Output

For Help, press F1 NUM

start EST Outine.doc - Mi... Example3.est - Empi... EST Microsoft PowerPoin... Desktop 3:27 PM Saturday

EST Input



Example 3 SOUTH CAROLINA STATION 2 EXTROPICAL EST INPUT F

Number	Historical	Rel. Prob.	Label	I1	I2	I3	R1
1	Historical	1.000	STORM_1H	1.165	0.972	1.095	2.125
2	Historical	1.000	STORM_1M1	1.030	0.972	0.968	1.988
3	Historical	1.000	STORM_1L	0.895	0.972	0.841	1.871
4	Historical	1.000	STORM_1M2	1.030	0.972	0.968	1.988
5	Historical	1.000	STORM_2H	1.165	0.351	1.095	1.524
6	Historical	1.000	STORM_2M1	1.030	0.351	0.968	1.397
7	Historical	1.000	STORM_2L	0.895	0.351	0.841	1.260
8	Historical	1.000	STORM_2M2	1.030	0.351	0.968	1.397
9	Historical	1.000	STORM_3H	1.165	0.549	1.095	1.702
10	Historical	1.000	STORM_3M1	1.030	0.549	0.968	1.575
11	Historical	1.000	STORM_3L	0.895	0.549	0.841	1.438
12	Historical	1.000	STORM_3M2	1.030	0.549	0.968	1.575
13	Historical	1.000	STORM_4H	1.165	0.600	1.095	1.753
14	Historical	1.000	STORM_4M1	1.030	0.600	0.968	1.656
15	Historical	1.000	STORM_4L	0.895	0.600	0.841	1.489
16	Historical	1.000	STORM_4M2	1.030	0.600	0.968	1.656
17	Historical	1.000	STORM_5H	1.165	0.616	1.095	1.759
18	Historical	1.000	STORM_5M1	1.030	0.616	0.968	1.642
19	Historical	1.000	STORM_5L	0.895	0.616	0.841	1.515
20	Historical	1.000	STORM_5M2	1.030	0.616	0.968	1.642
21	Historical	1.000	STORM_6H	1.165	0.760	1.095	1.913
22	Historical	1.000	STORM_6M1	1.030	0.760	0.968	1.786
23	Historical	1.000	STORM_6L	0.895	0.760	0.841	1.659
24	Historical	1.000	STORM_6M2	1.030	0.760	0.968	1.786
25	Historical	1.000	STORM_7H	1.165	0.690	1.095	1.823
26	Historical	1.000	STORM_7M1	1.030	0.690	0.968	1.716
27	Historical	1.000	STORM_7L	0.895	0.690	0.841	1.589
28	Historical	1.000	STORM_7M2	1.030	0.690	0.968	1.716
29	Historical	1.000	STORM_8H	1.165	0.483	1.095	1.616
30	Historical	1.000	STORM_8M1	1.030	0.483	0.968	1.509
31	Historical	1.000	STORM_8L	0.895	0.483	0.841	1.382
32	Historical	1.000	STORM_8M2	1.030	0.483	0.968	1.509
33	Historical	1.000	STORM_9H	1.165	0.925	1.095	2.078
34	Historical	1.000	STORM_9M1	1.030	0.925	0.968	1.951
35	Historical	1.000	STORM_9L	0.895	0.925	0.841	1.824
36	Historical	1.000	STORM_9M2	1.030	0.925	0.968	1.951

Extratropical storms

All historical with the same relative probability

I1 –multiplier of M_2 for spring, mean, neap

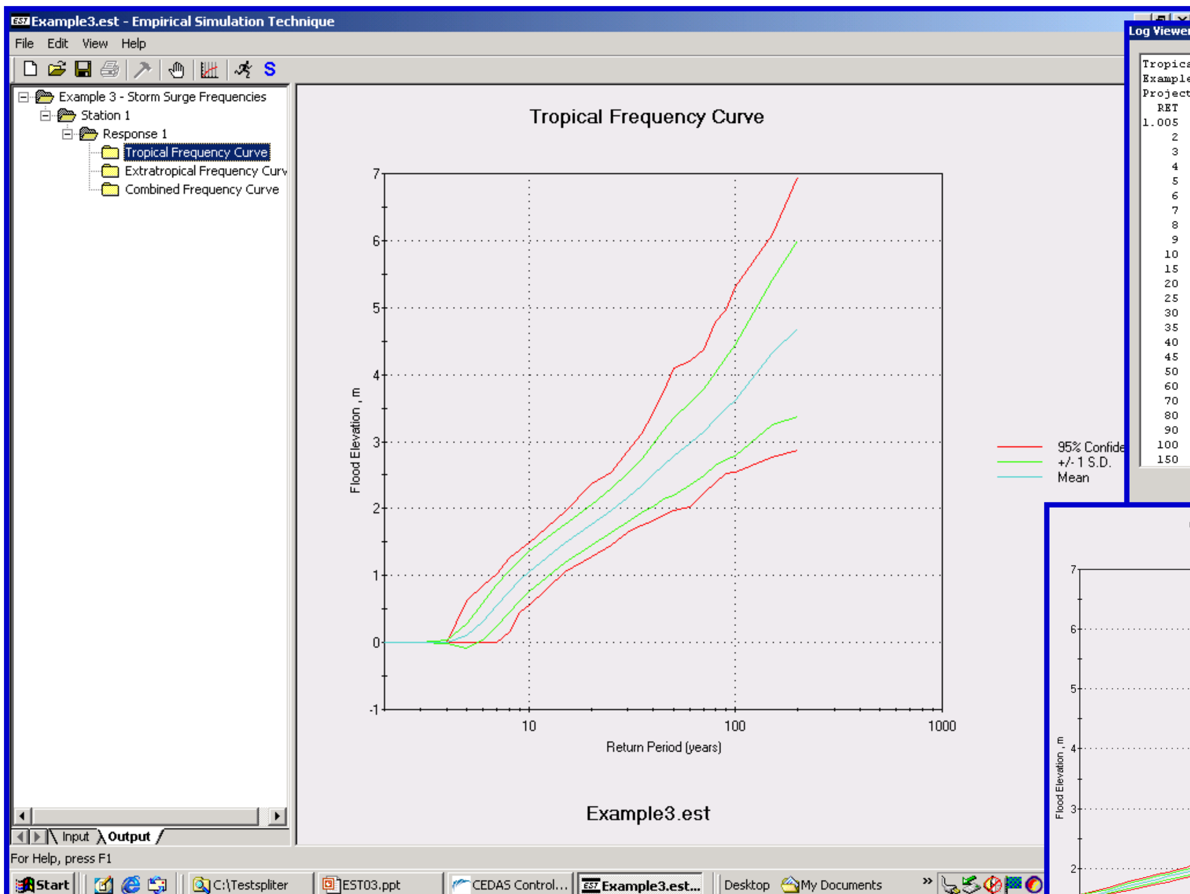
I2 – peak tidal elevation

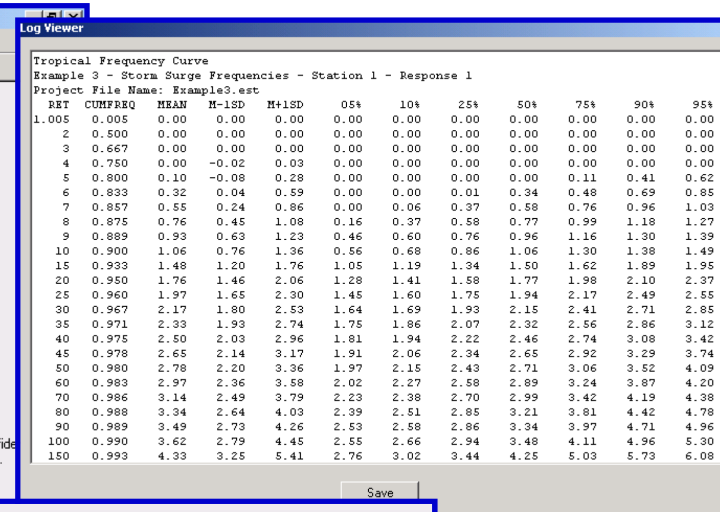
I3 – surge elevation with no tide

R1 – max water elevation

9 storms selected

SC Results





Log Viewer

Tropical Frequency Curve
Example 3 - Storm Surge Frequencies - Station 1 - Response 1
Project File Name: Example3.est

RET	CUMFREQ	MEAN	M-1SD	M+1SD	05%	10%	25%	50%	75%	90%	95%
1.005	0.005	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.500	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.667	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.750	0.00	-0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.800	0.10	-0.08	0.28	0.00	0.00	0.00	0.00	0.11	0.41	0.62
6	0.833	0.32	0.04	0.59	0.00	0.00	0.01	0.34	0.48	0.69	0.85
7	0.857	0.55	0.24	0.86	0.00	0.06	0.37	0.58	0.76	0.96	1.03
8	0.875	0.76	0.45	1.08	0.16	0.37	0.58	0.77	0.99	1.18	1.27
9	0.889	0.93	0.63	1.23	0.46	0.60	0.76	0.96	1.16	1.30	1.39
10	0.900	1.06	0.76	1.36	0.56	0.68	0.86	1.06	1.30	1.38	1.49
15	0.933	1.48	1.20	1.76	1.05	1.19	1.34	1.50	1.62	1.89	1.95
20	0.950	1.76	1.46	2.06	1.28	1.41	1.58	1.77	1.98	2.10	2.37
25	0.960	1.97	1.65	2.30	1.45	1.60	1.75	1.94	2.17	2.49	2.55
30	0.967	2.17	1.80	2.53	1.64	1.69	1.93	2.15	2.41	2.71	2.85
35	0.971	2.33	1.93	2.74	1.75	1.86	2.07	2.32	2.56	2.86	3.12
40	0.975	2.50	2.03	2.96	1.81	1.94	2.22	2.46	2.74	3.08	3.42
45	0.978	2.65	2.14	3.17	1.91	2.06	2.34	2.65	2.92	3.29	3.74
50	0.980	2.78	2.20	3.36	1.97	2.15	2.43	2.71	3.06	3.52	4.09
60	0.983	2.97	2.36	3.58	2.02	2.27	2.58	2.89	3.24	3.87	4.20
70	0.986	3.14	2.49	3.79	2.23	2.38	2.70	2.99	3.42	4.19	4.38
80	0.988	3.34	2.64	4.03	2.39	2.51	2.85	3.21	3.81	4.42	4.78
90	0.989	3.49	2.73	4.26	2.53	2.58	2.86	3.34	3.97	4.71	4.96
100	0.990	3.62	2.79	4.45	2.55	2.66	2.94	3.48	4.11	4.96	5.30
150	0.993	4.33	3.25	5.41	2.76	3.02	3.44	4.25	5.03	5.73	6.08

Save